The performing interaction between institutions and technology in the French power industry : the electronuclear success

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Among the various traditional "grands programmes" typical of the French public intervention in high-tech industries, the nuclear programme is often considered as one of the major successes. About 60 nuclear reactors have been built between 1970 and 1998. Altogether they generate 80% of the electricity produced by the state-owned monopoly at a competitive cost. Moreover, the French nuclear industry ranks first on the world market of nuclear equipment and services**.** Such performances are all the more contrasting with those in the other OECD countries, where costs have dramatically increased. Since the 1980s, world-wide electricity companies stopped their risky investments in nuclear equipment. Such a success is attributable to an appropriate institutional set-up, which has been able to enforce all the technological learning needed to the implementation of this kind of radical innovation. This appropriate set-up associated together (i) a strong political support, (ii) a state-owned electricity monopoly strongly identified to national interest, (iii) a very concentrated electromechanical manufacturing industry which supplies all the public procurement as well as (iv) an influent R&D public agency. Beyond this set-up, the success was due to the avoidance of past bureaucratic failures in technological policy and efficient coordination allowed by the centralised organisation of the system.

However in recent years, the French national nuclear system, as composed of the whole set of institutions and relations between organisations in this sector[1], is affected by different exogeneous shocks. In disorder those shocks are the European liberalisation directive, the persistence of the world-wide nuclear market depression, the competition of a new power generation technology (gas turbine), and the globalisation and concentration of the world-wide electromechanical industry. The national nuclear system cohesiveness is questioned, because it is forced to adapt to this new environment. But it resists thoroughly: power industry transposition of the European liberalisation directive, which could have dramatically upset internal relations, has been delayed and very limited in order to preserve the original technological choices.

We shall argue that the French nuclear system is a clear case of co-evolution of technologies and institutions. Generally speaking, techniques emerge from specific forms of industrial organisation but, once set up in a performing way, they contribute to maintaining the

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[1] National nuclear system as a sectorial part of the National System of Innovation could be considered as such, if it is considered within its relations to its institutional environment.

dynamics of these forms of this organisation (Nelson, 1988 ; Coombs et al, 1992). As far as electricity generation and network technology are concerned, the technological trajectory (increase in unit size, economies of scale, etc.) has effectively been oriented in the past by the organisational choices with respect to the creation of vertically integrated monopolies. In return, the technological dynamics reinforced the organisational form and the need for tight relationships between equipment suppliers and electricity companies: institutional path-dependency (North, 1988) has resulted from both the increasing efficiency of the institutional set-up to exploit technological progress opportunities and the growing interdependencies between institutions. As argued by Hirsh (1988), this organisation has also contributed everywhere to the initial commercial dissemination of the nuclear power technology, since regulated monopoly is the only one able to invest large amount of risky capital with very long lead-times. In the French case, moreover, this involvement was comforted by the traditional role of the national monopoly to pursue industrial and social policies (Frost, 1991).

But the coherence between technology and industrial organisation vanishes as soon as technical progress slows down or socio-economic environment changes (Nelson, 1988). So, in the power industry of many OECD countries, the social acceptance crisis of nuclear technology as well as the emergence of the much less capital-intensive gas turbine relax the co-determination and open up the institutional choice. Conversely, in France, the performances of the nuclear program help to maintain the nuclear option, thus justifying the preservation of the existing industrial organisation and institutional scheme. In order to characterise the joint institutional and technological dynamics of the French electricity supply industry we distinguish two stages: first the efficient adaptation of institutions and industrial relationships to the nuclear as a new technology, and second the influence of technological features on the industry structures changes.

1. The performance of the French public model: the compliance of the institutions with the requirements of nuclear technology

Nuclear technology is a complex and capital-intensive technology, requiring considerable development and learning delays. It also presents specific technological risks with strong symbolic charges. In all the industrialised countries, it originally benefited from a favourable selection environment: highly structured public research and development, monopolistic organisation of the electricity industry, a high technological dynamism in the electromechanical industry world-wide, and an atmosphere of enthusiasm for science and technology values.. Standardisation was favoured through the innovation process. It consisted in initial creation of variety at both world-wide and national level thus favouring competition and emulation. It was then followed by a race to the equipment size and the early selection on the international market of a dominant design, the American Light Water Reactors (LWR)

However, changes in social environment in the industrial democracies have dictated that technology should be able to adapt to increasing safety demands and subsequent regulatory requirements. Barriers to equipment completion and regulatory instability have disrupted the various learning processes. Against this background of instability, the most effective national nuclear systems were doubtless those that have been able to avoid instability and to allow the reactor technique to be standardised (Finon, 2000). France was in this position for three reasons: strong public and centralised institutions, the capacity of the national nuclear system to open to foreign technology adoption, and efficient user-producer relations.

1.1. The industrial and economic performances

The importance of the sales and the control of the economic costs reflect the technological and industrial success of the French nuclear industry since 1970. The French industry has built a nuclear capacity of 62 000 MW in France and 6 000 MW in foreign countries, that represents 22% of the world-wide nuclear capacity (outside the former Soviet block). Between 1975 and 2000, it has won 40% of orders on the international reactor market (although this market was increasingly narrow). It could supply all the services of the nuclear fuel cycle from the uranium mine to the fuel reprocessing. In the seventies it also took the leadership in the technological development of second generation reactors, the Fast Breeder Reactor (FBR), before the cancellation of OECD countries programs in the eighties.

Table 1: Comparison of nuclear investment reference costs in various countries in 1984, 1992 and 1997 (in current $ / kW)

	USA	Japan	Germany	France	United Kingdom
1984	1,860-2,800	1,405	1,429	870	nd
1992	2,320-2,500*	2,938	3,417	1,658	3,540-4,080
1997	2,079*	2,828	nd	1,988	nd

* Official American costs for 1992, like those of 1997, are purely for information, as they do not relate to any specific projects. In some nuclear projects, investment costs reach $4000/kW.

Source: IEA-OECD– Projected costs of generating electricity-1986, update 1992, update 1998.

The economic control of nuclear technology is shown in investment costs that are dramatically less than those recorded in other industrialised countries: 80% to 100% less than in other countries[2]. The construction time was controlled (5 years for a 900 MW reactor and 6 years for a 1,300 MW reactor, compared with 8-10 years in other countries). Performance levels in operation, although sometimes affected by generic faults, are also satisfactory[3].

1.2. Centralised organisations and institutions of the French nuclear system

The network of actors responsible for developing nuclear energy is a close-knit one, and was for some considerable time closed to political influences and managed on a centralised basis. Since 1975, the three key actors are Electricité de France (EDF), the public electricity enterprise, Framatome, the reactor seller and the Atomic Energy Commission (CEA) the nuclear research and development agency, , which also owns the COGEMA, the nuclear fuel company. The Ministry of Industry played a central role in co-ordinating and taking decisions on most industrial structuring features. This organisational model is deeply rooted in the tradition of the “grands programmes”, which was a principal characteristic of the French national system of innovation until the eighties.

- **The public electricity enterprise**

EDF was nationalised in 1946. The decision was taken to create a single integrated monopoly in order to overcome the failure by private enterprises to develop major equipment in a co-ordinated way, and to pursue the objectives of industrial and social development. This function has remained despite the passing of decades (Frost, 1991). The offer of equipment and fuel to the national utility has always been considered by the government to be mastered,

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[2] Increases in costs were recorded because of increases in the stringency of standards and site restraints, but they were much less than would otherwise have been the case.

[3] Availability rate: 71% in 1992, 81% in 1995.

especially for the purpose of consolidating the electromechanical construction industry and promoting national technology. The utility strongly identified itself to this mission. The size of EDF (present turnover of $ 30 billions) gives it large capacity for action. On the opposite of many electricity utilities in the world, it has a vast engineering department (about 4,000 members of staff) and develops large-scale research and development activity by its RD division in partnership with manufacturers. These resources have allowed it to master the construction of complex equipment and to dictate the direction taken by its suppliers' activities in the field of innovation.

- **The equipment supply industry**

During the 1950s and 1960s, unlike the American and German industries, which were concentrated and technologically dynamic, French equipment suppliers were small and widely scattered, and depended on foreign licences. There were no firms capable of offering power station in turnkey contract. The firms were protected by public procurement rules but were subject to EDF's technical choices and to its willingness to keep several suppliers in competition with each other. Under these conditions, the sector was not concentrated until the end of the 1960s. Since 1975, the industry was definitively concentrated: on Alsthom, a subsidiary of CGE (later Alcatel) for the supply of turboalternators under the General Electric and Brown-Boweri licences, and on Framatome, subsidiary of Creusot-Loire group, which supplied the nuclear reactors under the Westinghouse licence until 1985. The ownership of the capital of Framatome, divided after 1985 mainly between the Atomic Energy Commission (35%), EDF (10%) and CGE (40%)[4], gave the State an important right of veto.

- **The Atomic Energy Commission**

As in Great Britain and the United States, the pioneer countries in nuclear developments, the government created in 1945 a public body known as the Commissariat à l'Energie Atomique (CEA) The CEA had very wide-ranging responsibilities for developing both civil and military applications for nuclear energy. The CEA always aimed at placing itself in the centre of the network of industrial actors involved in the development of reactors and fuel cycle techniques. By vocation, it strongly advocates national technologies. (Scheinman, 1965 ; Nau, 1974). In 1970, the industrial choices made (abandonment of national reactor technology) led to a review of its responsibilities, but without the radical changes that similar bodies underwent elsewhere (UK, USA, Italy, etc.). Together with its RD functions on new types of reactors, it in fact preserved a strong industrial involvement in all sections of the nuclear fuel cycle, with its subsidiary COGEMA, and a significant stock participation in the reactors seller FRAMATOME. In addition, it holds the capacity of expertise on which is based the decisions of the ministerial safety authority, and has retained its military activity, with the result that its legitimacy is continuously maintained in the civilian nuclear activity.

- **Modes of co-ordination**

The nuclear programme is written in the context of a long centralised tradition of public involvement and planning that has little exposure to politics and, as such, allows very long industrial programmes to be fulfilled (Zysman, 1982 ; Cohen and Bauer, 1986). A decisive role also has to be attributed to the technocracy, composed of engineers belonging to the

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[4] The Creusot-Loire group bankrupted in 1984.

"Corps d'Etat" (Corps des Mines, Corps des Ponts). Strongly identified to the national interests, their members have overall responsibility at the ministerial authorities (especially Ministry of Industry), and are strongly represented in EDF's, the CEA's and the nuclear sector businesses' heads and top-management staffs. Given the French fuel poverty, since the Suez crisis in 1956 and the oil crisis in 1973, the reduction of the French energy dependence became the cardinal objective. In this sociological context, from 1956 to 1981, a commission bringing together the various parties in the government and industry (the PEON Commission) made the major determinant choices relating to nuclear policy in a closed way. Thosechoices have been subsequently endorsed by the Government.

In the same way, the nuclear safety authorities, which had a crucial role to play in the development and stabilisation of techniques, remained integrated into the bodies responsible for promoting nuclear technology (Ministry of Industry, the CEA) until 1999. The regulatory style was part of this centralist tendency, as was the simplicity of licensing and control procedures and the willingness to make the safety rules foreseeable.

- **The result: a inexorable industrial momentum**

After a first stage made of conflicting learning, the nuclear policy gains an irresistible industrial momentum. The first period of the civil nuclear effort was nationalist by nature. Developments related to the Uranium Naturel Graphite Gaz (UNGG), reactor technique, which was originally developed by the CEA for military plutonium production. Eight reactors, (with a total capacity of 1,600 MW), were ordered and built between 1955 and 1970 by EDF being its own industrial architect. After five years of conflict between EDF and the CEA, the resignation of General de Gaulle in 1969 allowed American LWR techniques to be adopted, as EDF wished to adopt them in order to benefit from the dominant design advantages (Bupp and Derian, 1978).

The second period (1970-1975) was marked by the construction of the first four Pressurized Water Reactors (PWR) (under Westinghouse licence) and two Boiling Water Reactors (BWR) (under General Electric licence), and by industrial concentrations supervised by the ministry. In 1975, The government chose a definitive industrial rationalisation with a single supplier of PWR reactors (Creusot-Loire and its subsidiary Framatome) thus eliminating the CGE[5].

The third period (1975-1983) was opened by the oil shock of 1973. It was marked by the construction of several series of standardised PWR reactor, with an average of five orders per year despite the initial lack of learning. Unwavering political support, and the centralised institutions, protected the development of equipment against the effects of social opposition. In this same dynamic, the technological effort invested in the development of the Fast Breeder technique was increased by the construction of the Super Phenix prototype between 1978 and 1986, with the aim of becoming the leader of the second generation of reactors. Given this strong industrial momentum, the last period (1983 onwards) was marked by a long slowing in the frequency of orders (one reactor every two years between 1986 and 1992) in spite of significant EDF's overcapacity, and by the adoption of a new design (the 1,450-MW N4 type), not subject to the Westinghouse licence.

1.3. Relevant industrial choices

[5] The two BWR orders to CGE were cancelled by 1975. In exchange CGE concentrated all the turboalternators manufactoring.

French nuclear industry has developed from an initially weak industrial basis, comparatively to the American and the German industries. Conversely, the British nuclear program was based on an analogous set of institutions and organisations but has shown poor performances (see box 1). This may suggest that good industrial and technological choices at relevant time allow the creation of a performing nuclear industry able to compete with the leading ones. These appropriate industrial and technological choices are :

- The adoption of the American dominant technology,
- The user's renunciation of a dominant relationship over suppliers.

- **The adoption of the American dominant technology**

In such a set of institutions and organisations, the risk could have been to favour "nationalist" goals to the detriment of industrial and commercial realism as some French technological programs in the sixties overran (supersonic aircraft Concorde, big computer in the Plan Calcul, Aerotrain in railways, etc.). The French nuclear industry has been less affected by technological nationalism essentially because of the EDF influence. The presupposition that mastering a national reactor technique would give a local industry an advantage in world-wide competition did not have the same resounding in France and in Great Britain. In France, the public company and the industrial firms preferred being in the dominant technological stream, by relying on the supposed capacity of American industrial leaders in electrical equipment supply to master the technology of reactors, rather than remaining bound to the CEA's UNGG technique and its drawbacks. Despite the pronounced anti-American sentiment that characterised the de Gaulle period (1958-1969), EDF was able to refuse to take on new UNGG reactors between 1963 and 1969[6] before the governmental decision.

In Great Britain, technological nationalism in the nuclear field has put the industry at a serious disadvantage. The influence of the nuclear agency on the government prevented the LWR from being adopted by the public company, less legitimate than EDF, on two successive occasions (1965 and 1974). In addition it caused the very premature launch of the new British Advanced Gas-cooled Reactor (AGR) technique in 1965 to avoid LWR adoption with eight programmed order, and this in turn caused numerous industrial and technological difficulties (see box).

BOX 1
The British nuclear program

In Great Britain nuclear technology has been promoted by a similar network of actors than in France, that is, a public electricity enterprise with a high level of engineering capacity (the CEGB), a fragmented equipment industry which by 1970 was concentrated around two vendors (GEC and NEI), and a nuclear agency (the Atomic Energy Authority or AEA) which exerted a very significant influence.

The British nuclear programme was the first to develop in the world, being based during the first stage on the graphite-gas Magnox stations, 27 of which were successfully built between 1954 and 1970 (4,200 MW). The second stage, on the other hand, was very poorly managed. The AEA, which was very active in the study of several different types of reactor (Magnox, AGR, heavy water, FBR), tried to impose its own technological choices prematurely in order to prevent the CEGB from adopting the American LWR technique in 1965. A programme for eight 660-MW AGR reactors was launched on the basis of technological knowledge that was too limited. The orders were allocated between three weakly integrated consortia, and the result was an industrial

[6] At the same time, EDF was allowed to circumvent the ban imposed on the transfer of American technology to France to allow familiarisation with it. It had two PWR reactors constructed successively by Framatome in Belgium, at Chooz in 1962 (230 MW reactor) and at Tihange in 1967 (670 MW reactor) in the framework of two French-Belgian joint ventures.

fiasco (costs doubled, construction took between 10 and 13 years, availability levels were mediocre) (Burn, 1978; Williams, 1980). Despite this fiasco and the development of the oil resources from the North Sea, however, the nuclear option remained credible. The choice of national technology was again retained in 1974, against the wishes of the constructor GEC and the CEGB's preference for PWRs. The AEA insisted on a programme of heavy water reactors, replaced in 1978 by the order for two now fully mastered AGR reactors. At the beginning of the 1980s, the decision was finally taken to switch to PWRs for building one reactor per year, but a unique reactor was finally ordered in 1988. Because industrial learning, it costed twice a similar reactor built in France.

However, the abandonment of the gas-graphite UNGG reactor did not signify in France the end of the technological and industrial nationalism that was ardently defended by the CEA. But a series of compromises was reached between the industrial and commercial realism to which EDF and the reactors manufactured were required to submit on the one hand, and the continual technological push of the CEA on the other hand. This led to the choice to "Frenchify" the PWR reactor in the context of a tripartite programme (CEA-Framatome-EDF) between 1977 and 1982, mainly in order to finally escape from the American government control on the exportation of nuclear reactors under American licence. This led also to the commitment to build the prototype Fast Breeder Super Phenix in 1978, in spite of the increasing bleak future of the international nuclear market (Finon, 1989). When the decision was taken, none of these choices supposed increased costs for the manufacturer or for EDF[7], which could accept easily to sacrify to the "national technology" support.

- **The utility's renunciation of a dominant relationship over suppliers**

In Great Britain, the public company preferred preserving competition between electrical equipment suppliers to save on costs. Industrial policy was not in favour of a rapid concentration of the electrical equipment industry. Orders for the eight AGR reactors were sent to three weakly integrated consortia in 1965. After the 1970s' concentrations of electrical equipment suppliers (GEC and NEI), concentration of the reactor manufacturing was not achieved until 1973 in spite of the technological fiasco.

In France until 1975 EDF, which had been dominating its national suppliers from the beginning, shared the same belief in preserving competition between suppliers (Frost, 1991). However, during the 1960s, this approach came into obvious contradiction with the requirement to concentrate the industry. Although between 1968 and 1970 it encouraged polarisation around two or three groups in electromechanical equipment, it subsequently wished to keep them in competition on the national market. When the government imposed complete concentration in 1975, in accordance with the concept of "national champion", EDF had to agree to alter this pattern. The industrial concentration was criticised because of the profit that the monopoly supplier was likely to realise from its serial sales. EDF, however, admitted that the gains allowed by the series effect and standardisation resulting from this concentration largely offset the advantage that could have been taken by bringing two national reactor suppliers into opposition.

The evolution of the user-supplier relation has also been marked by indirect effect of the adoption of technology under Westinghouse licence. In fact, it limits the user's interference inside the design of reactors and their components. French series of PWR until 1985 were strictly under the Westinghouse design for the 900 MW and the 1300 MW size. In the UK, by comparison the utility participation to the design of the successive AGRs is pointed as one of

[7] For example, EDF financed only one quarter of the total cost of SuperPhenix ($ 3,5 billion), one half having paid by foreign partners and the last quarter from the public budget.

the factors of the industrial fiasco (Thomas, 1997). So EDF brought its strong management capacity to monitor building works, but without power to destabilise designs.

1.4. The capacity of the industrial organisation to standardise nuclear technology

The level of technological and industrial performance of the French nuclear industry can be broadly explained by the capacity to standardise the very large reactors and alternators in the context of series orders and to master the way in which works are carried out. These grouped orders allowed the components and the "design" of the whole to be standardised to a significant degree, the benefits of the series effect to be the limited lead-times for licencing and the learning associated with each change of design to be reduced. Two factors condition this capacity for standardisation: regulatory stability and industrial concentration.

First, the institutional closeness of all the safety authorities, which shows in a flexible regulatory style, has allowed the technique to be stabilised through the stability of safety rules for each series. In other countries (USA, Germany, Japan, etc.), the learning process has been curbed by the difficulty in anticipating regulations and the impossibility to stabilise the techniques because of recurrent changes in safety rules. These rules were applied to reactors under construction, causing a backfitting requirement that necessitates very costly alterations.

Second, the presence of a single reactors seller, together with that of a single large electric operator with major engineering potential, has allowed the successful completion of series of reactors in the context of several major contracts (so-called CP1, CP2, P4, and P'4).

Table 2: Contracts of series of standardised PWRs

Contracts	Signature	Number of reactors	Unit capacity	Characteristics
Prog. 70 CP1	1970-1974 April 1974	6 18	900 MW 900 MW	Westinghouse design 3 loops of steam-generators Coupling of pair of reactors
CP2	December 1975	10	900 MW	Decoupling of pair
P4 P'4	December 1975 August 1980	8 12	1300 MW 1300 MW	Westinghouse design 4 loops of steam-generators
N4	1984, 1987, 1991, 1993	4	1450 MW	French design

Being its own industrial architect, EDF was in the best position to organise the interface between the reactor and the electric part of the station. At the same time, as just noted, Framatome's dependence on a foreign licence limited EDF's involvement in the design of reactors under the four major contracts. The decision was explicitly taken to adhere rigidly to the Westinghouse design. The role of EDF was however no less essential: it was in charge of the rigorous checking procedures for equipment delivered, the quality control procedures, and the effective site management of building works.

In the other major industrialised countries (USA, Germany, Japan), the fragmentation of the electricity industry and the presence of numerous industrial groups competing against each others limited both the possibility of standardising the reactors and the users' capacity to monitor the building works. In the United States, the reactors construction are all different in practical terms, with one type of reactor per constructor (1 BWR, 3 PWR) and different adaptations of design to suit each company's needs and the regulator's demands.. This can be explained by the fragmented electricity industrial structures (180 utilities) with four competitor industrial groups (General Electric, Westinghouse, Babcock & Wilcox, Combustion Engineering) involved in nuclear engineering. , The "utilities", which were small and did not have any capacity to manage building works[8], depended on the major industrial architects (Bechtel, etc.), who were paid on the basis of “cost plus” contracts and therefore had no incentive to rationalise the management of the projects subjected to continual regulatory changes (S. Thomas, 1988). Absence of standardisation and of series effect, difficulties in reducing the destabilising effect of backfitting: the contrast with the French nuclear system shows the importance of industrial centralisation and of the quality of the user-producer relation in the successful commercial dissemination of nuclear reactor techniques.

To sum up, nuclear technology requirements fit ideally with the institutional matrix of the French SNI. It requires centralisation, a capacity for industrial planning, highly co-ordinated effective industry and regulatory stability. Finally, beyond the paradox of an industrial success founded on foreign technology, the producer-user relationship has been the determining factor in the learning dynamic.

2. The capacity of resistance of the French electronuclear institutions to exogeneous shakes

Both the technological, industrial and institutional environment of the French electronuclear system has dramatically evolved with the last 15 years.

- As with other public utility sectors, the electricity supply industry (ESI) of most significant economies have been progressively facing radical reforms whose key element is the replacement of monopoly with competition. In the European Union, the Directive 96/92 compels the countries to liberalise their ESI. This challenges the traditional user-producer relations in the electric equipment market. Competition in the ESIs has strong influence on the generators’ criteria of equipment choices, on their participation to R&D expenses and to the long learning processes in new nuclear technologies. The new competitive environment is not favourable to nuclear option.
- Regarding the electrical techniques and components, the stop of nuclear reactors dissemination in the OECD countries induced a technological re-orientation of the major equipment suppliers towards the new Combined-Cycle Gas Turbine (CCGT). Thanks to its rapid efficiency progress, its low capital intensity, its low demanding user’s engineering capacity, CCGT technology has been progressively chosen by an increasing number of electric utilities in the world because it fits with the new competitive environment ;
- Regarding the evolution of industry structures, there has been a significant concentration of the world-wide electrical equipment sector. Only few groups have resisted among which ABB, General Electric, GEC-Alsthom (now Alstom), Mitsubishi, and Siemens altogether bound by licence agreements. They have dramatically increased in size and globalised their activities as a results of all the mergers and acquisitions. As a consequence, these concentration and globalisation movements also lead to the abolition of the national frontiers and the emergence of a standard technology (presently the CCGT)

Submitted to these external shocks, industrial organisation benefits in France from strong elements of institutional path-dependency rooted in the nuclear option. We shall show how the realms of legitimising conventions and the intertwining of industrial and bureaucratic interest allowed the conservation of the integrated organisation of the ESI, as this system produces performing results. This avoids then the future dilution of nuclear supporting institutions, as it could be observed in the UK where the ESI liberalisation has clearly dilutes them. However increasing globalisation and regional integration of the French economy has

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[8] One exception was the Duke Power Company, which successfully mastered the construction of its equipment.

slackening effects in the relations between the parties in the national nuclear system. While competition between electrical techniques does not allow any optimistic prospects for nuclear equipment in the OECD countries on the mid-term, the institutional answer has been a recent public reconcentration of the French nuclear industry.

2.1. The stability of the nineties

During the nineties, the relations between the main players remained quite stable in France. Two nuclear orders have been placed by EDF in 1991 and 1993 in spite of the electric overcapacity, thus supporting the manufacturer. Since 1991, anticipating the need of replacement of EDF’s nuclear reactors in the long term, Framatome has been working on the design of an advanced PWR, the so-called European Pressurised water Reactor (EPR), with financial support from EDF and technological support from the CEA. This project also responds to its positioning strategy on the future world reactor market with a technique competing with the new ABWR of General Electric. In the near future the slight power industry reform (see below) preserves the government means to promote the EPR prototype realisation and to organise its financing, for preparing the first orders planned around 2010.

In parallel the industrial and technological resources which have been acquired by the French nuclear industry gave some impetus to break up the nationalist industrial insulation. The government let Framatome establish an alliance in 1990 with Siemens to develop the EPR, initially in view of its common commercialisation on the world market. This technological venture leads in 1999 to the merger of the two companies’ nuclear divisions.

As for the public nuclear agency, the CEA is protected by the legitimacy of its military activities and the cohesiveness of the ”Corps d’Etat” to which the CEA top managers belong. Altogether, this avoided any attempt to radically re-organise it, Actually, a thorough evaluation in 1989 did not even recommended such re-organisation. The only significant evolution in RD relations has concerned, since 1985, the participation of the technology users (EDF, COGEMA, Framatome) into the financing of RD projects decided jointly with them[9].

The closure of SuperPhenix FBR prototype in 1998 has questioned the RD priorities. But the abandonment of the FBR priority does not significantly modify neither the public nuclear RD, nor the CEA’s role within the French technological policy, whereas, at the exception of Japan, public nuclear RD has strongly declined in the other major industrialised countries since 1985.

Table 3 – Evolution of public nuclear RD budgets* (in millions $ and in constant prices 1996)

	1985	1990	1996
USA	1079	628	116
Japan	2056	2565	2821
Germany	996	251	70
France	nd	514	594

[9] In 1995, for instance, industrial users brought $ 220 millions to the civil nuclear budget of the CEA which amounts at $ 870 millions (1995 Annual Report).

UK	427	171	15,8

*without fusion

Source – IEA, Energy Policies of IEA countries - 1998, Paris, OECD.

The long-term policy issues (climate change, nuclear waste management) justify maintaining nuclear RD despite the bleak future of the world-wide nuclear capacity development on the mid-term. The redefinition of according objectives (such as the reduction of waste volumes by new types of reactor, new nuclear fuels, "sustainable" nuclear reactor, etc.) is still under discussion in 2000. But the stability of the power and nuclear industries in the next years should allow avoiding dramatic decline.

2.2. The nuclear option, main element of institutional path-dependence in the French electricity reform conservatism

Differences in approaches to liberalising and restructuring the ESI have resulted in a diversity of reforms among the many countries that have implemented their own reforms. Both the structures of the industry prior to the reform and the institutional environment, among which the nuclear option, condition the attractiveness and the extent of liberalisation reform (Glachant and Finon, 1999). France and the UK had quite similar industrial structures. Nuclear power promotion was a common goal of the two governments but it impacted very differently on the choices of industrial structures, market rules and institutions.

2.2.1. The French conservative reform of the electricity supply industry

France opted for institutional conservatism with no radical restructuration and no creation of any kind of organised market. France chose to limit competition to bilateral contracts between producers and industrial consumers (one third of the retail market) through the third party access provision to the national utility's transmission network. Indeed, it preserves vertical integration as far as possible under public ownership. Instead of a full vertical de-integration, there is only a transparent separation of the transmission and system operation within EDF, which then has to ensure non-discriminatory access to the transmission network. The creation of a regulatory commission with credible powers is supposed to guarantee fairness in the competition. Since there is neither significant structural changes nor creation of organised markets, competition will take the form of market contestability. However, EDF keeps its over-dominant position, which should dissuade potential entries.

The reform, voted lately in 2000, has been designed mostly to preserve intact the role of the state-owned monopoly as an instrument of public policy in different areas, mainly the energy policy with nuclear option. Moreover it gives legal means to create a market-niche for new nuclear equipment. The Law contains articles giving the ability to the government to control the evolution of the overall electric production capacity and its technology mix. Indeed, it sets up a five-year programming procedure which has to be debated (and voted) by the Parliament. It allows the government to tender for the construction and the operation of specific additional generating capacities whose technology will be clearly specified, with long-term guaranteed outlets and bid-price payment for the winners. The law creates also a fund financed by a tax on every generated kWh so as to support all the expenses devoted to public interest missions. So it could be used to finance the overcost of the new nuclear units production in the market-niche.

On the opposite, pioneer of power liberalisation in Europe the UK opted in 1990 for a radical restructuring, the creation of a centralised day-ahead spot-market, privatisation of the public utility CEGB, and a mix-policy of defence of the nuclear power and promotion of CCGT. The activities of the CEGB have been split between four companies: three generators among which one public nuclear producer, and one transmission company. The British government commitment in the nuclear option to limit dependence from coalmines influenced the restructuration and the transitional dispositions for supporting the nuclear power production (Thomas, 1996). The British government organised institutional devices to support existing nuclear production and protect eventual new nuclear investment. One measure, the Non Fossil Fuel Obligation (NFFO), was the requirement that the distributors must buy specified proportions of their power from non-fossil sources (i.e. nuclear power and secondarily renewables). A second measure was the payment of a tax on electricity purchases (the Fossil Fuel Levy or FFL when then represented around 10% of the final electricity price) financing the expected high operational costs of existing reactors (including the provisions for decommissioning) and particularly the overcosts of eventual future reactors[10]. But in fact these arrangements were more fragile than the preservation of the utility's vertical and horizontal integration opted in France to protect the nuclear option.

2.2.2. Past nuclear performances as elements of institutional conservatism

The past institutional arrangements in electricity have had an influence over the technological and industrial performances. Those performances systematically self-reinforce in France the institutional arrangements which allowed them while the institutional environment is itself very receptive to them and able to occult inefficiencies. On the contrary, the British institutional arrangements became more fragile as much as technological and industrial inefficiencies appeared while the neo-liberal ideology was progressing in the 80s participating to such "unstability".

Obviously, in France, the nuclear power technological and industrial success did legitimise both the size and the state-owned status of EDF. These two characteristics have allowed the development of high-levelled engineering competencies and stable strategic decisions, which exploit a range of economies of scale. They could be presented as acting in the long term in favour of consumers (Bouttes and Lederer, 1991). But in the same time, the technocratic decision process and the political consensus surrounding the success of the nuclear power program hide inefficiencies and maladjustments. Economic effects of generic flaws, counterpart of positive series-effects, are occulted, as the absence of economic improvements with technological changes (size increase to 1300 MW and 1450 MW, use of mixed uranium-plutonium fuel). [11] Unadaptation of costs are also ignored: as the national nuclear system is

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[10] Same as with FFL, these non-fossil electricity was known to be exclusively nuclear power at that time but it progressively included renewable. Nuclear Electric, the public nuclear producer, earned through this FFL more than £1 billion each year which represented 40-50 % of its income

[11] The drawback of the reactor standardisation is the vulnerability of the nuclear reactors fleet to generic flaws. The standardisation advantages have been real, but economic risks associated to those flaws have rarely been assessed. They impacted at three times on different components, steam generators, control rods, etc. with important costs (losses of production, reparation costs of hundred of millions of F per reactor).
The closed decision process tends also to occult the adverse effects of engineers' beliefs. As such, the reactors' size increase between the 900 MW-reactors and the 1 300 MW reactors did not produce the expected reduction in investment costs while it reduced availability performance; the latest type of reactor, the so-called N4, has shown some important learning problems which have, up until now, not been clearly analysed. Be that as it may, the overall efficiency of the program is considered as largely compensating every drawback of the system rigidity.

not easily adaptable, excess capacity resulted from the poor ability to adapt to the dramatic slow-down of power growth: in 1990, it could be estimated at 12 000 MW out of a total 54 000 MW nuclear capacity by that date[12].

For that matter, there is an important contrast between the French and the British case. Whereas the public electricity company succeeds in the UK in increasing its economic performances during the 1980s, the defaults of its equipment policy will strongly contribute to its full break-up (both vertically and horizontally). It has not the possibility to refer to the success of the nuclear program: the reactors production (20% of the total in 1990) is modest comparatively to the EDF's one. At that time, negative liberal critics regarding state-ownership were rather strong and powerful. They emphasised a number of factors that have led to inefficiencies such as the systematic over-estimation of electricity growth forecasts, the over-investment and the excessive, if not blind support of nuclear power. More generally, they have denounced the public management inefficiencies (Vickers and Yarrow, 1988). Numerous learning difficulties with turbo-alternators of 500 MW ordered between 1965 and 1980 and the construction of AGR reactors give arguments to the critics. Even if the Thatcher Cabinet was strongly supporting nuclear power, those mistakes warned enough people who do not defend against the privatisation in 1988.

In France, though, the past technological and industrial success acts in favour of the preservation of the vertically integrated utility and more generally of a protected institutional arrangement. As such, the preservation of the conditions to promote nuclear power to build new units and favour learning on a new type of advanced PWR was considered as a priority, even if it had to be associated with some kind of institutional conservatism.

2.2.3. **The institutional requirements of the nuclear option as regards to electricity competition**

Nuclear power is very demanding in terms of safety and investments. As such it is not an attractive technology for private investors in a competitive electricity industry. The introduction of effective competition at the generation with divestiture and privatisation of nuclear assets would suppose massive changes in the French technocratic and political culture which is still based on two beliefs to this respect:

- the necessity to maintain within the same State-owned producer the operation of nuclear equipment so as to guarantee high levels of safety, given that 80% of the French power production is based on the fleet of nuclear reactors ;
- the unacceptability to depend significantly on fuel importation for the electricity generation, while competition should favour much less capital intensive technology as CCGTs which would furthermore require massive gas importation.

This last postulate is backed to the technocratic culture which, unfamiliar with risk, tends to dramatise the vulnerability of any dependence situation, thus justifying the preservation of the state-owned vertically integrated monopoly. By contrast other countries poorly endowed in fuel resources (Spain, Italy, Sweden) have implemented radical reforms of their electricity industry without being so influenced by sensitiveness to the dependence risk.

[12] Excess capacity has been occulted by the accelerated decommissioning of recent conventional plants, the promotion of electricity usages and the contracts on electricity exportation (60 TWh of net electricity exportation in 1998)

2.3. The preservation of the French electronuclear institutions : avoiding their dilution under the competition and globalisation shakes

The resistance to the competition paradigm avoids the risk of dilution of the nuclear institutions after the instauration of power competition, as it has been observed in the UK. However evolution should be seen more complex because of the necessity of adaptation to external changes: the French ESI is included in the increasingly integrated and liberalised European power industry and the French electromechanical industry does not escape to the globalisation of this sector.

2.3.1. The importance of avoiding the competitive shake-up in the ESI

The British contrast sets off the positive influence of institutional conservatism in the electricity reform upon the stability of French electronuclear institutions in the nineties, as for the future. If keeping opened nuclear option had clearly oriented initial choices of restructuring the power industry in the UK, afterwards the competition paradigm has progressively eroded rationales for the nuclear support. The NFFO niche rapidly became no more than a mechanism to ensure that the existing nuclear power plants were used to their full extend instead of promoting the construction of new plants. In 1994, after a review on its policy, the government decides a moratorium on new nuclear construction and announces privatisation of the AGRs and PWR assets. The rationale was the prospect that existing AGRs could potentially generate at low costs but that new plants are financially risky and uneconomic. After privatisation British Energy, the new private nuclear producer, does not effectively need any support. NFFO and the fossil fuel levy subsidisation were removed by 1998. But no investor shows any interest for new nuclear equipment.

The reform introducing competition has also eroded the nuclear institutions by its own logic in the UK. The promotion of the competition, which is the main mission of the regulator, implied to favour entries, and so to encourage new entrants to invest in CCGTs thus considered appropriate for this new competitive environment[13]. In other words, the development of competition brought government to encourage the dissemination of another technology. Moreover the choice of the major generators to invest massively into CCGT turned upside down the relationship between purchasers and suppliers**.** There is no preference for national equipment suppliers anymore since orders are won through a tendering process: the joint venture GEC-Alsthom indeed wins less than 20% of the tenders[14]. The major generators have also abandoned their own RD activity for new electrical techniques and the financing of public nuclear RD projects. The nuclear agency, already transformed in public commercial establishment in 1986, was strongly affected by the breakdown of the joint public and private RD financing[15]. Among these ruins the nuclear fuel company BNFL survives firstly by the reactor fuelling market. It is the only company staying active within the British

[13] For this goal, long term contracts (15 years) were allowed between developers and distributors in tension with the principles of the jurisprudential competition rules.

[14] ABB and Siemens were the main winners.

[15] The nuclear public R&D budget decreases dramatically from $ 170 millions in 1990 to $26 millions in 1996. Source : International Energy Agency.- Energy Policies of IEA Countries.- 1990 and 1998.

nuclear industry[16].

So the British case demonstrates that, as the upset of industrial organisation in centralised ESI has devastating effects on the nuclear institutions and relationships. Conversely, the absence of such an upset in France should contribute to their stability in the general context of liberalisation and globalisation.

2.2.3. Uncertain futures and statist reconcentration answer

Despite the preservation of the integrated public utility, the relationships between participants of the French nuclear system are somehow affected by the European economic integration, the globalisation and increasing concentration of electric equipment supplies. Reinforcement of financial and strategic links between industrials involved in the nuclear industry inside the public sphere has been the answer to future uncertainties.

- **The relaxing of the relationship between EDF and the equipment supply industry**

The relationships between EDF and the reactor manufacturer are relaxing for different reasons:

- The 1992 European Directive on "public procurement" opens these markets to international competition, thus prohibiting national preferences
- There should not be any effective need for new nuclear plant within the next 15 to 20 years for the French electricity market is mature if not in excess capacity. If it does not open opportunities of CCGT development on one hand, it also does not favour new nuclear projects
- EDF is obliged to adopt a competitive behaviour: It has to respond to the threat of foreign entries on the market and it aims at massively investing in Europe for controlling companies and extending its market share.

The 1999 internal reorganisation within EDF illustrates such strategy. Its newly created Commercial Division ("pôle clients") ranks first supplanting the Generation Division ("pôle industrie") and its engineering department regarding strategic power and influence on the traditional EDF's equipment push. EDF pursues an aggressive internationalisation. As a consequence, it is less invested with support of the French nuclear and electromechanical industry. Subsequently, EDF is not as enthusiastic as it used to be in ordering a prototype EPR which would suppose to go partly alone to great expenses, given that new reactors would not have to be ordered before 2015. Besides, EDF aims at taking advantage of its existing amortised nuclear assets by working on the extension of their lifetime over the expected 30 years to 40-45 years, that postpones the renewal of the French reactor market. More generally, possible institutional convergence of the French power industry with the other European ESIs during this latency could question prospects of new nuclear order by that time.

- **Progressive break-up between the national nuclear system and the globalised French**

[16] It took the opportunity of the sale of their nuclear divisions by Westinghouse in 1998 and ABB in 1999 to vertically integrate from the nuclear fuel to the reactor supply. Still, BNFL has little hope to have reactor sales outlets in the UK. It took the opportunity of the sale of their nuclear divisions by Westinghouse in 1998 and ABB in 1999 to vertically integrate from the nuclear fuel to the reactor supply. Still, BNFL has little hope to have reactor sales outlets in the UK.

equipment industry

The restructuring of the nuclear industry responded to the growing concentration of the international electromechanical industry, the long-lasting depression of the international nuclear market and the subsequent sales by some major companies of their nuclear divisions (namely Westinghouse and ABB). The traditional nationalist and technocratic logic behind the persevering nuclear momentum has recently induced a separation between first the nuclear industry reconfined into the statist-industrial area and second the equipment supply industry fully involved within the global market.

- Alcatel, which owned 44% of Framatome shares without having the full control, decided in 1999 to get out the nuclear activities by selling its capital share. Since 1985, under the influence of the State-engineers bodies, successive governments have refused to let it take over the full control of Framatome, to the respect that French technology could be sold out if opportunities of strategic alliances were going to force it. Facing such a resistance, Alcatel focuses on its electrical equipment activities, essentially gas turbines on which it is strongly involved in its joint venture with the British GEC, and without any support from orders on the national market. Globalisation of Alsthom increased : by the end of 1999, GEC-Alsthom (now Alstom) decided to rationalise the whole range of its activities by merging their electrical equipment activities with ABB Power, the two companies aiming to regroup their technological resources for performing their innovation activities. Ultimately Alstom buys all the ABB Power's assets in April 2000.

- Framatome is subsequently replaced in the public area. As far as Framatome was in line with the nationalist logic, the Ministry of industry was allowing its relative strategic autonomy. For instance, Framatome has been able to pursue a diversification strategy towards activities in the field of the "connectic" which now represents half of its turnover. But it has kept close eyes on the strategic alliance with Siemens, which was in 1989 originally based on the only joint conception of a new type of reactor for sales outside Europe. It also has raised objection to the Framatome's will of purchase of Westinghouse Nuclear in 1998. It accepted the merger of Framatome's and Siemens' nuclear divisions in 1999, because the French part is clearly dominant (with two thirds of the joint venture assets). After all, in 1999, Alcatel's withdrawal resulted in a situation where both COGEMA and the CEA were given the control of Framatome[17]. It corresponds to a takeback from the State which aims at protecting the French technological and industrial resources in the nuclear activities in the hope of a new world-wide nuclear market take off.

3. Conclusion

French nuclear success has benefited from the specific institutional set-up associating together the public power company, the equipment supply industry, the nuclear agency and the government.

Dominated by the national utility French industry, in the dominant technological stream at the right moment. This avoided insulation on one hand and the user's or nuclear agency's intrusion in the reactor manufacturer's learning process on the other hand. As a consequence

[17] The new Framatome stock sharing in 2000 is the following : COGEMA 34% ; CEA-industrie 32%; EDF 11% ; Alcatel 14%, for Framatome salarees, 5% (with a rest of 4% to share).

of centralism, regulatory stability and buyer’s unicity allowed series of technological developments (standardisation, effects of series) that made economic success possible. Success was mainly obtained on industrial grounds without using a natural technology, while new technological developments (N4, FBR) on a purely national basis will not be convincing.

Technology and industrial organisation have clearly interacted in France in the preservation of the electricity industry organisation. Nuclear option justifies the slow and limited scope for liberalisation, which then avoids the dilution of the national nuclear system. Its structures remains an exception regarding both the electricity area (preservation of a quasi-monopoly with strong engineering activities) and the nuclear R&D. It thus helps to keep in France the same technological trajectory, which is oriented towards more complex large-sized and capital intensive technology. The risk is to be isolated from the rest of the other industrialised countries by developing new technologies if there will be no new take-off of nuclear technology dissemination in the mid-term. The globalised French electrical equipment industry chooses to separate from the national nuclear system. But one issue still remains: how far is it possible to introduce more flexibility into the French system without breaking it up?

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